ARIZONA STATE UNIVERSITY
http://activetectonics.asu.edu
http://lidar.asu.edu/

Utilization of LiDAR / ALSM Point Cloud Data for Earthquake Geology and Tectonic Geomorphic Mapping, Analysis, and Visualization

Christopher J. Crosby and J Ramon Arrowsmith
Department of Geological Sciences, Arizona State University, Tempe, AZ 85287

GEON CYBERINFRASTRUCTURE FOR THE GEOSCIENCES

I. ABSTRACT

The growing availability of LiDAR (Light Distance And Ranging (a.k.a. ALSM - Airborne Laser Swath Mapping)) data in the earthquake geology and tectonic geomorphology communities means that these powerful data are being utilized in an increasing number of research projects. LiDAR point cloud data (x, y, z, return classification) are challenging to manipulate, so users typically only take advantage of interpolated surfaces (digital terrain models; DTMs) generated by the LiDAR data vendor for their analysis. However, by not returning to the LiDAR point cloud data, users may fail to fully explore the richness of these data sets.

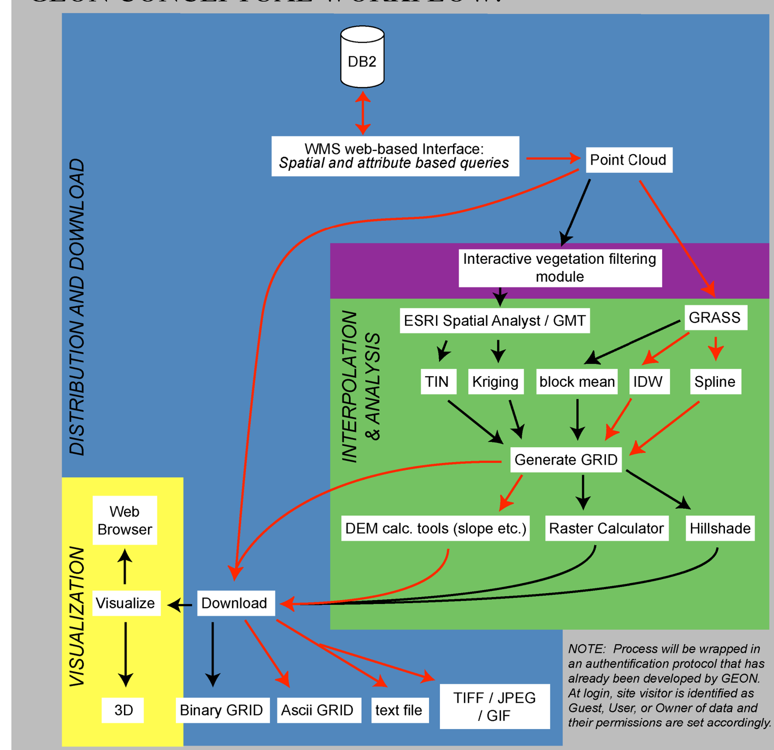
Initiating geomorphic analyses and visualizations with the point cloud gives users more understanding of the data and control over how those data characterize the landscape. Details such as the interpolation algorithm and grid resolution can significantly affect the manner in which the resulting DTM represents the landscape. In addition, beginning with the LiDAR point cloud data allows the user to assess the point density of the data in the area of interest. By understanding the variation in ground-return density (which can vary due to topography and canopy characteristics), the user has a better understanding of potential artifacts that may be introduced into their DTMs by this variation. Finally, working with LiDAR point cloud data, both by themselves and in tandem with DTMs, opens a new range of possibilities for the visualization of these data.

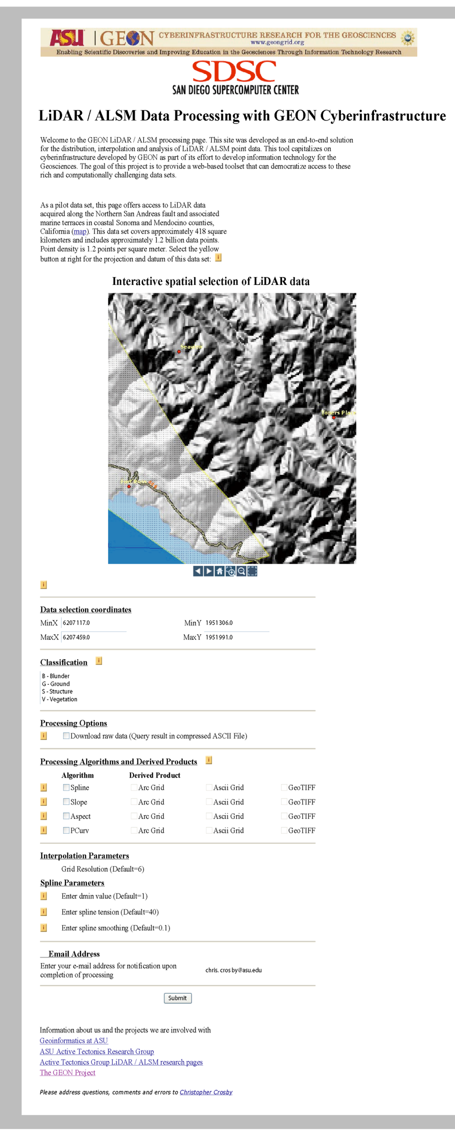
Using LiDAR point cloud data from the Northern San Andreas Fault and Western Rainier Seismic Zone recently made available via the GEON LiDAR Workflow (GLW) (http://www.geongrid.org/science/lidar.html), we focus on optimization of the spline interpolation algorithm, available in the GLW. By tuning the smoothing and tension parameters in the spline algorithm as well as the grid resolution we demonstrate how landform representation in areas of low-density ground returns can be enhanced. Examples of mapping and visualization of faults and tectonic landforms in these data demonstrate the utility of interactive interpolation of LiDAR point cloud data. Through interactive interpolation, tectonic landforms may be delineated more efficiently and with greater detail than by working with the vendor generated DTMs.

II. GEON LiDAR WORKFLOW

Using GEON cyberinfrastructure we have developed an internet-based LiDAR processing workflow to distribute, interpolate, and analyze LiDAR point cloud data. This workflow was conceived as an end-to-end resource to allow users to fully explore these rich yet computationally challenging data sets. With the availability of LiDAR point cloud data via the GLW, the types of data analyses presented here are now significantly easier.

GEON CONCEPTUAL WORKFLOW:





IMPLEMENTATION:

The GEON LiDAR Workflow (GLW) provides interactive spatial and attribute-based selection of LiDAR point cloud data via a simple internet-based interface. Users can choose to download the point cloud data or perform processing tasks such as interpolation to Digital Terrain Model (DTM) and calculation of basic geomorphic metrics.

Currently the GLW hosts three data sets:

- Northern San Andreas Fault and associated marine terraces
- West Rainier Seismic Zone
- Faults in the Eastern California Shear Zone

ACCESS THE GLW:

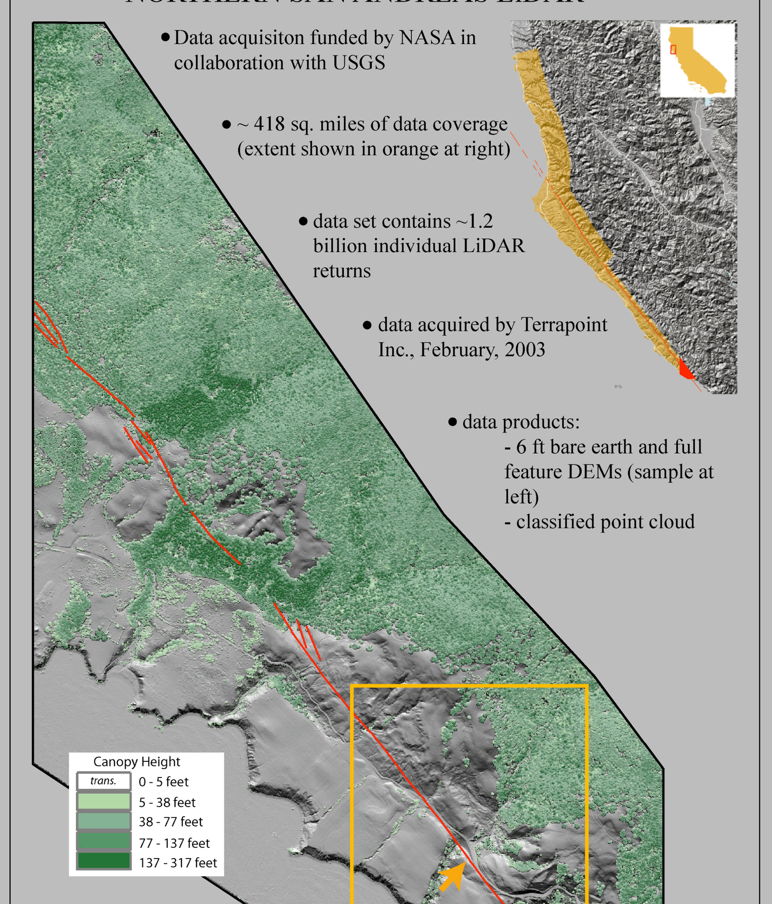
http://lidar.asu.edu/

http://www.geongrid.org/science/lidar.html

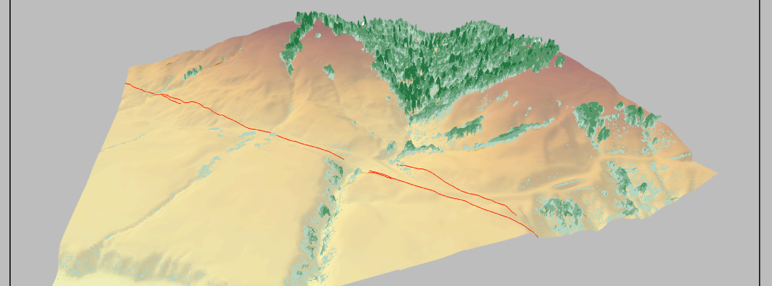
III. POINT CLOUD VISUALIZATION AND POINT DENSITY ACCESSMENT

NORTHERN SAN ANDREAS LiDAR

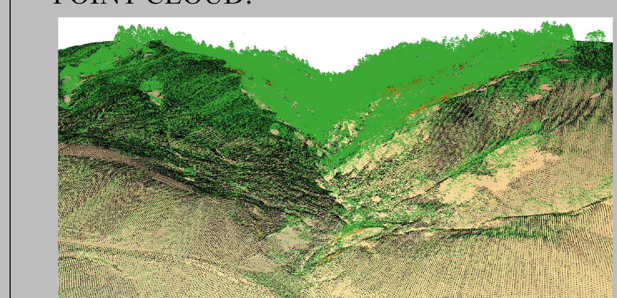
- Data acquisiton funded by NASA in collaboration with USGS
- ~ 418 sq. miles of data coverage (extent shown in orange at right)
- data set contains ~1.2 billion individual LiDAR returns
- data acquired by Terrapoint Inc., February, 2003
- data products:
  - 6 ft bare earth and full feature DEMs (sample at left)
  - classified point cloud



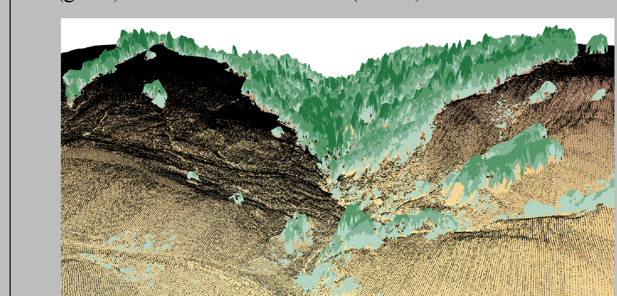
above: Hillshade of a portion of the 6 ft full feature DEM produced from the Northern San Andreas LiDAR data. Approximate area of this figure is shown in red in the overview map above-right. In this image the vegetation has been colored to illustrate canopy height - darker shades of green indicate taller vegetation. The orange box shows the extent of the data used for analysis in this portion of the poster. The orange arrow shows orientation of 3D perspective views. Active trace of the San Andreas is shown in red. ***below***: 3D rendering of LiDAR data within the orange box above. The ground surface is show in shades of brown, vegetation is shown in shades of green based on height.



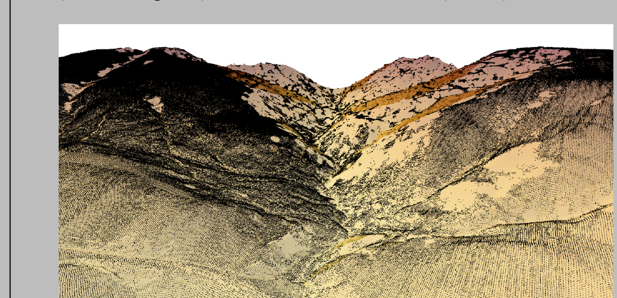
POINT CLOUD:



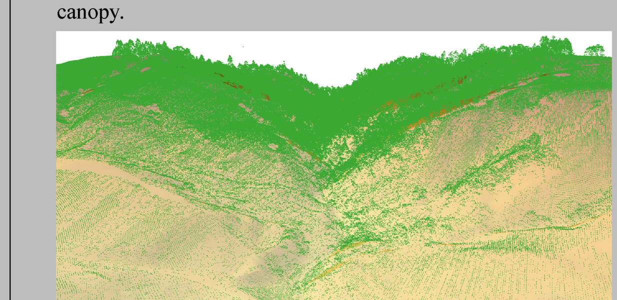
3D rendering of ground returns (black) and vegetation returns (green) over the bare earth DEM (brown)



3D rendering of ground returns (black) and vegetation DEM (shades of green) over the bare earth DEM (brown)

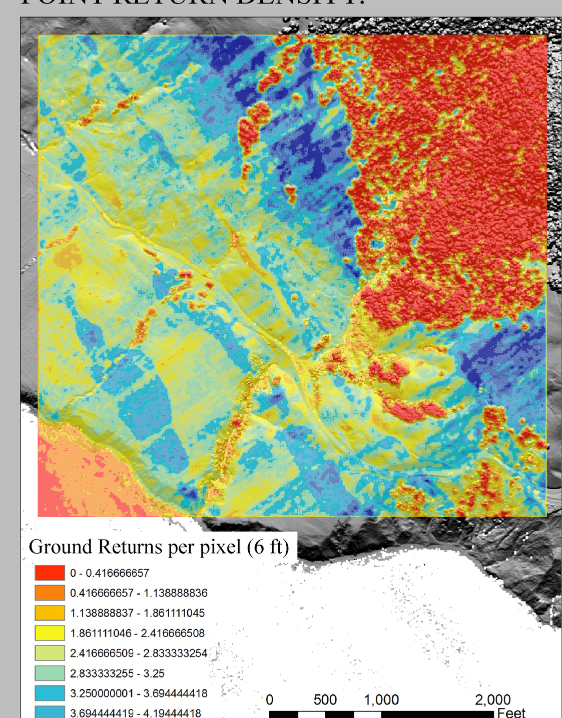


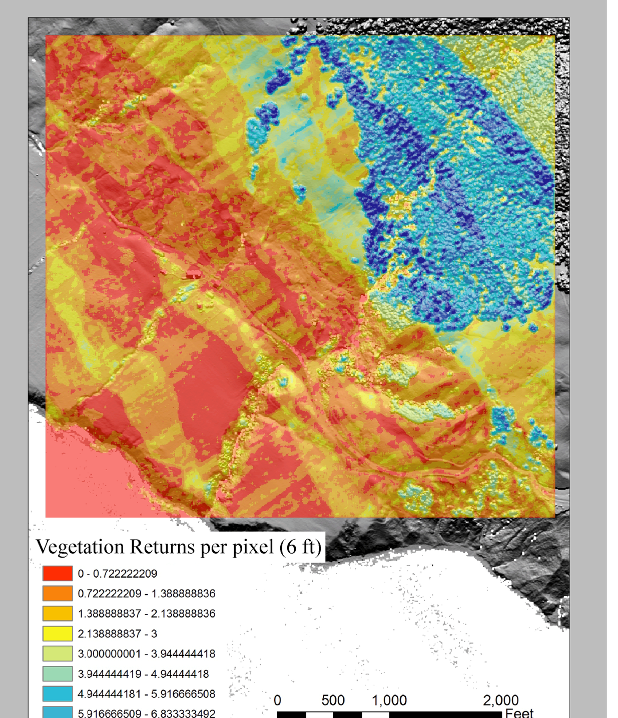
3D rendering of ground returns (black) over the bare earth DEM (brown). Note the lack of ground returns underneath the canopy.



3D rendering of vegetation returns (green) over the bare earth DEM (brown). Note returns classified as vegetation on the flat surfaces in the foreground. These points are misclassified, reclassifying them as ground returns would yield higher ground return densities in these areas.

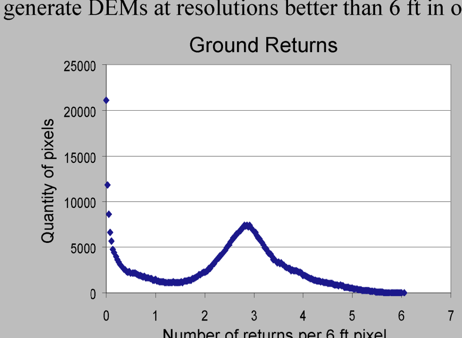
POINT RETURN DENSITY:

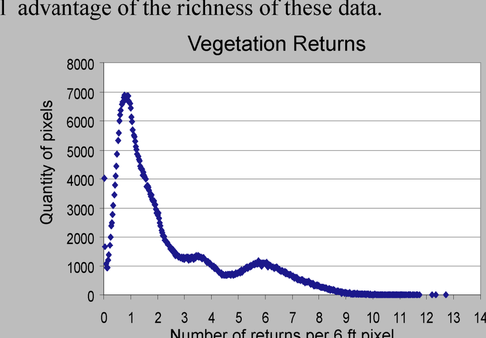




The figures above show the number of LiDAR ground (*left*) and vegetation (*right*) returns for each 6 ft pixel in the DEM. Note the limited vegetation returns on the flat, grass-covered, marine terraces and high return density (up to 12 per pixel) in the heavily forested drainages. Also note the very low number of ground returns (< 1 per pixel) beneath the forest canopy. This lack of ground returns beneath dense vegetation is likely due to poor penetration of the LiDAR pulse through the canopy and the point classification algorithm.

The plots ***below*** show the distribution of points per pixel for both ground and vegetation returns. Note that the majority number of 6 ft pixels have 2 more ground returns. This suggests that in certain portions of the data set, it may be possible to generate DEMs at resolutions better than 6 ft in order to take full advantage of the richness of these data.





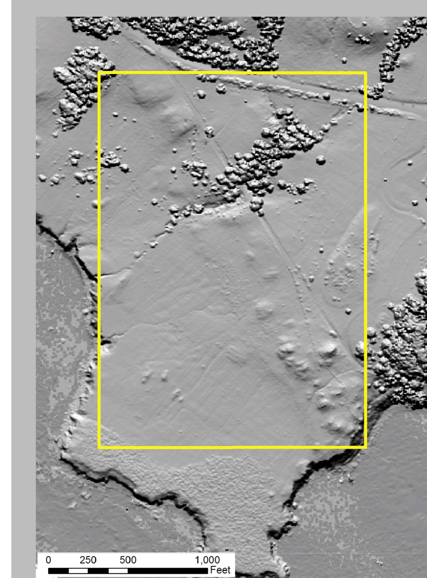
SUMMARY:

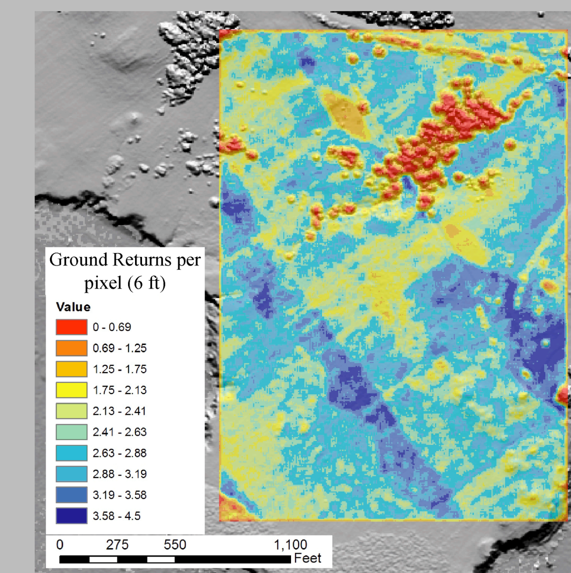
Visualization and analysis of LiDAR point cloud data before initiating geomorphic studies yields insight into issues such as (1) homogeneity of ground returns, (2) density of ground returns and (3) point cloud misclassifications. With an understanding of these issues, users can optimize DEM resolution and interpolation algorithm (see section IV at right) to best represent the landforms and processes of interest.

VI. GENERATION OF DIGITAL ELEVTAION MODELS FROM POINT CLOUD DATA

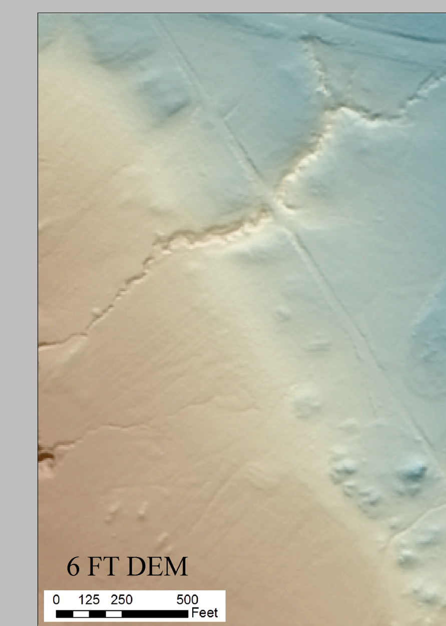
SAMPLE DATA SET:

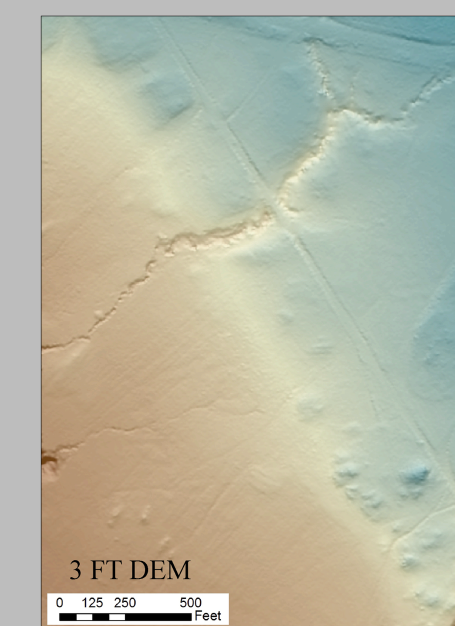
In order to explore the generation of digital elevation models (DEMs) from LiDAR point cloud data a subset of the Northern San Andreas LiDAR data was selected. This data set contains ~280,000 ground returns. Its extent is shown in the yellow box below left. This region was selected because it is largely unvegetated and has a high density of ground returns (below right).

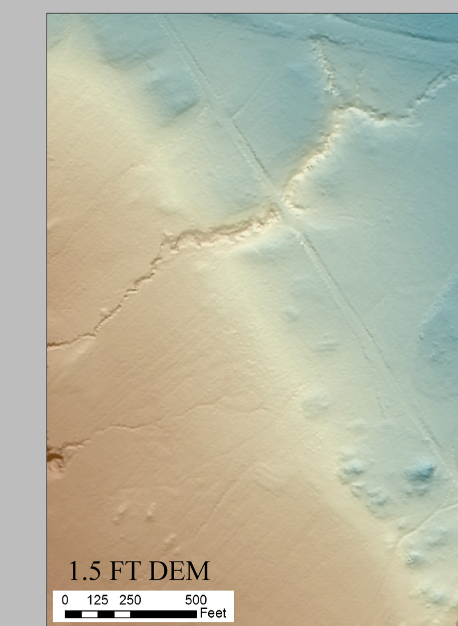




DEM RESOLUTION:

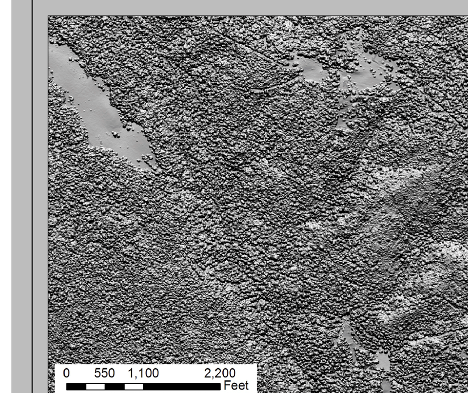


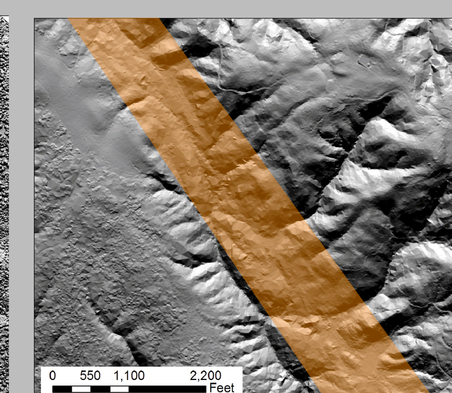




The images above show the subset of NSAF LiDAR data shown at left interpolated to DEM at different resolutions. All three images were produced with the spline interpolation algorithm available through the GEON LiDAR Workflow. The left, 6 foot, DEM is the same resolution as the vendor provided DEMs and is what most users of this data set would typically utilize. The center and right images show the increased landscape detail revealed by generating higher-resolution DEMs. Given the point per pixel density shown at left, the 3 foot DEM takes better advantage of the richness of the LiDAR data then does the 6 foot DEM. The 1.5 foot DEM likely oversamples the data given the point per pixel density.

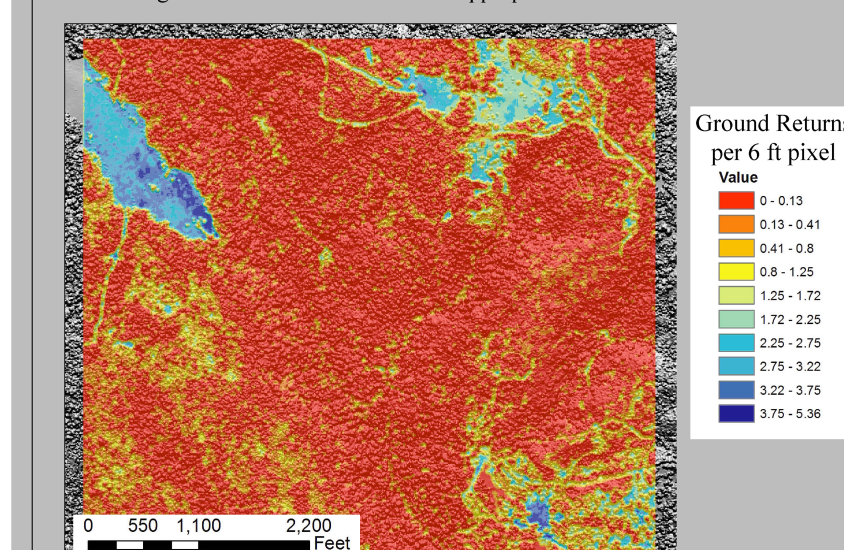
DEM GENERATION IN AREAS OF LOW GROUND RETURN DENSITY:

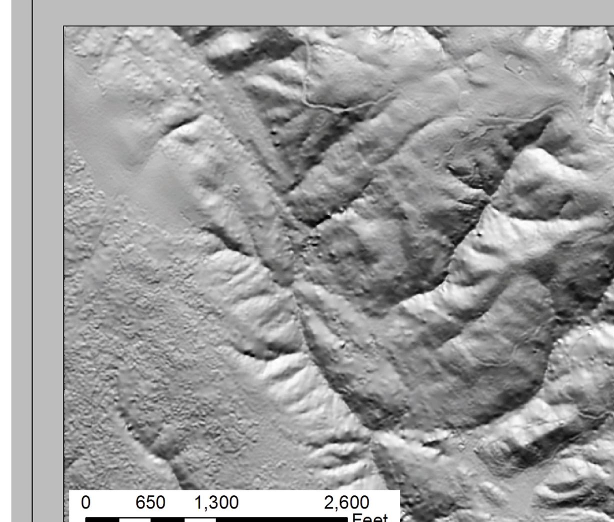




The images above show a portion of the NSAF LiDAR data that is characterized by very dense forest canopy on steep slopes. The San Andreas fault zone crosses the images from the upper left to lower right (orange box). Much of the NSAF is located in regions like the one shown above. Although the LiDAR data helps to reveal the geomorphology of the SAF fault zone, the density of ground returns in these areas is poor. When these data are interpolated, lack of ground returns results in artifacts such as the triangular facets (associated with the TIN interpolation used by the data provider) visible in the right image. Changing interpolation algorithm and/or parameters my enhance the landscape representation in these areas.

Image below shows the number of ground returns per 6 foot DEM pixel. Note that in most of the forested areas there is less than one ground return per pixel. Interpolating these data at resolutions greater than 6 feet would not be appropriate in this case.

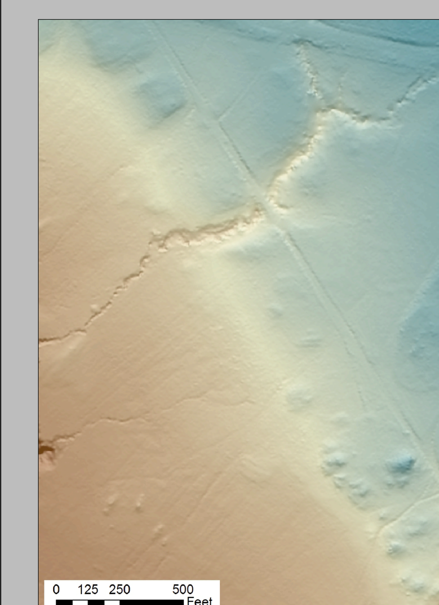




The image at left shows the same LiDAR point cloud data (~301,000 points) as in the upper panel interpolated to a 6 foot DEM using the spline algorithm available in the GEON LiDAR workflow. The spline algorithm does not produce the large facets associated with the TIN. However, the extent to which the SAF fault zone geomorph is enhanced by the spline is open to debate. Users working with these data may wish to further explore the role of interpolation algorithm and parameters in low-ground return environments.

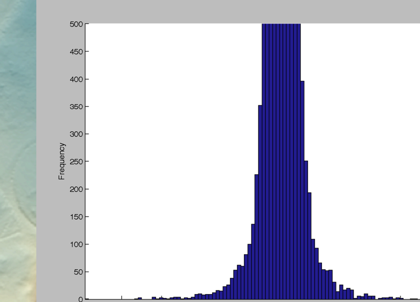
COMPARISON OF COMMON INTERPOLATION ALGORITHMS:

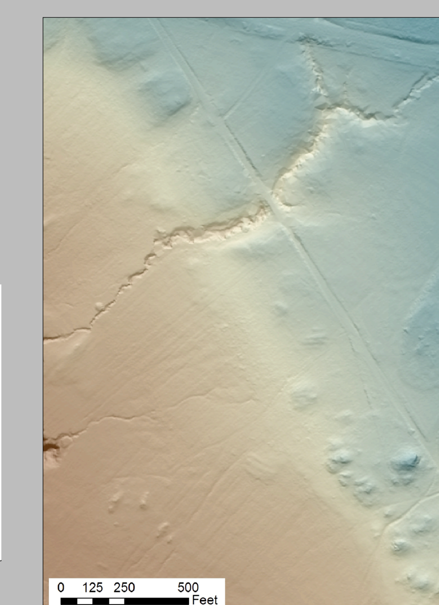
The images below explore the accuracy of common DEM interpolation algorithm to fit the LiDAR point cloud. Each image is a 3 foot DEM produced with one of four interpolation algorithms. The elevation of the grid at each of the 280,000 individual ground return points was then extracted from the DEMs to test the fit of the surface to the original ground returns. The histograms below show the difference between the points and the surfaces. The mean and standard deviation is also shown.



SPLINE

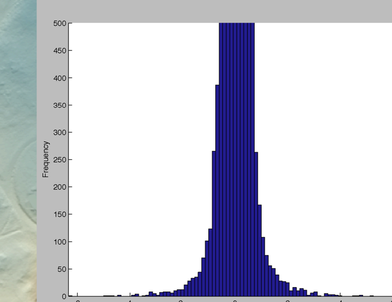
Mean: 0.0259
Standard Deviation: 0.2746

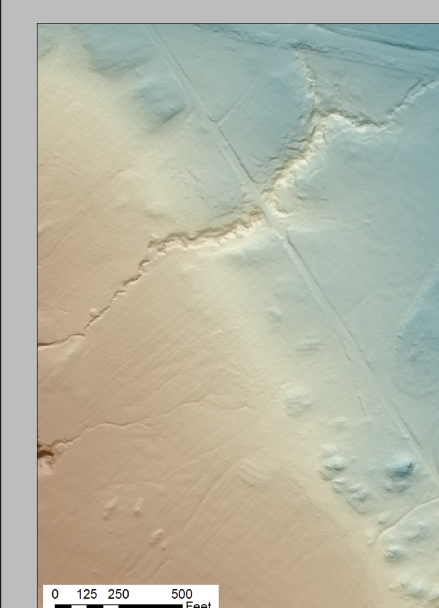




TIN (Triangular Interpolation Network)

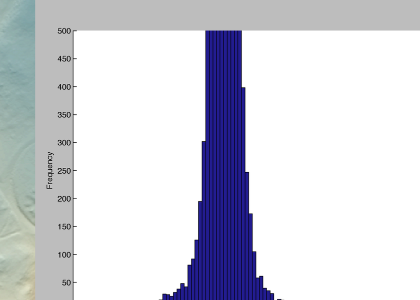
Mean: 0.0084
Standard Deviation: 0.1682

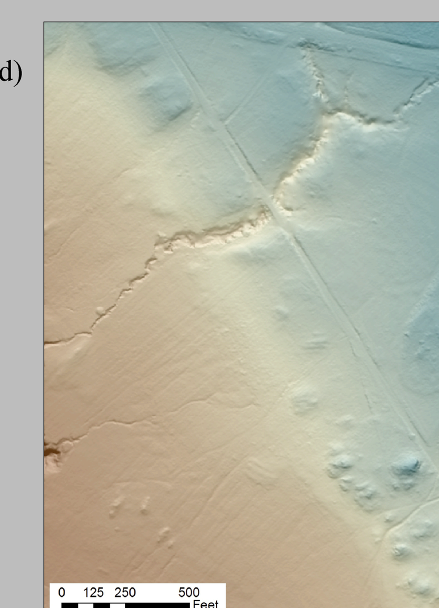




IDW (Inverse Distance Weighted)

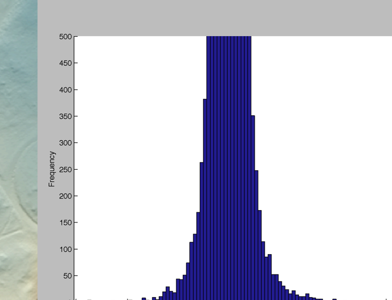
Mean: - 0.0032
Standard Deviation: 0.1471





KRIGING

Mean: - 0.0048
Standard Deviation: 0.2291



SUMMARY:

- Beginning geomorphic analysis with LiDAR point cloud data instead of the standard, vendor generated, digital elevation models allows the user to optimize the interpolation resolution, algorithm and parameters to enhance landscape representation.
- Knowledge of ground return point density provides insight into what resolution DEM the data set will allow - this is especially important in regions where topography and vegetation canopy may reduce ground returns.
- In areas of high-ground return density, there is little variation between interpolation algorithms in the accuracy with which they fit LiDAR ground returns.

This material is based upon research supported by the National Science Foundation under Grant No. 0225543 (GEON) and the National Earthquake Hazards Reduction Program under Grant No. 06HQGR0032